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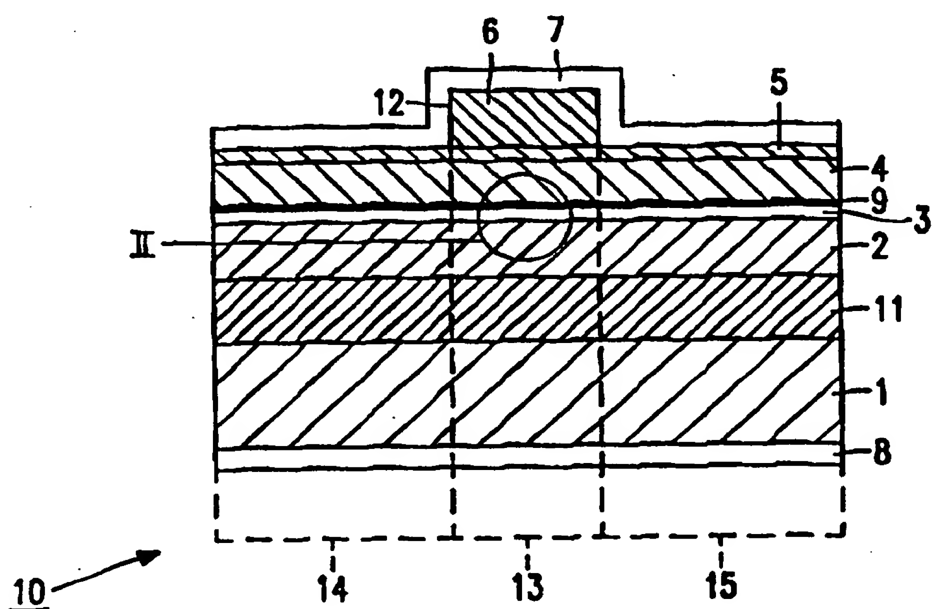

(57) Abstract

A radiation-emitting semiconductor diode with a substrate (1) on which are situated: a first cladding layer (2), an active layer (3), and a second cladding layer (4), forms an important component in information-processing systems such as optical disc systems, especially when constructed as a laser. A laser in the GaInP/AlGaInP material system has a desired short-wave emission of, for example, 630 nm. According to the invention, such a diode comprises a barrier layer (9) which is present between the second cladding layer (4) and the active layer (3) and which prevents dopant elements, for example zinc atoms, from moving from the second cladding layer (4) t the active layer (3). The degradation which would otherwise occur was found t be connected with a local displacement of the pn junction from the second cladding layer owing to the stress in the layer structure which is necessary f r the photoelastic effect. The barrier layer (9) preferably comprises tw or more sub-layers (9A, 9B) with alternately a high and a low bandgap, in the GaInP/AlGaInP material system made of AlGaInP or AlInP with alternately a high and a low aluminum content. Such a barrier layer at the same time increases the efficiency of the diode according to the invention. In a major embodiment, the d ping profile has a stepped gradient on either side of the active layer (3).

Radiation-emitting semiconductor diode, and method of manufacturing such a diode.

The invention relates to a radiation-emitting semiconductor diode, in particular to a semiconductor diode laser often called laser hereinafter for short, comprising a semiconductor body with a semiconductor substrate on which are present at least in that order a first cladding layer of a first conductivity type, an active layer, and a second cladding layer of a second conductivity type opposed to the first, the first and second cladding layers being provided with means for the supply of an electric current and with a pn junction which, given a sufficiently high current strength in the forward direction, is capable of generating electromagnetic radiation in a strip-shaped active region of the active layer, while the surface of the semiconductor body is provided with at least one covering layer which is under mechanical stress and the surface of the semiconductor body or the covering layer is geometrically structured such that, and the mechanical stress of the covering layer is chosen such that the effective refractive index for the generated radiation is reduced in the active layer on either side of the strip-shaped active region. The invention also relates to a method of manufacturing such a diode and to a method of operating the laser version of such a diode.

Such a radiation-emitting diode, especially when constructed as a laser and when the wavelength of the emission lies in the visible range of the spectrum, forms a particularly suitable radiation source for inter alia information processing systems such as laser printers with which information is written, and such as optical disc systems in which information is read, for example so-called Compact Disc (CD) and Video Long Play (VLP) players, or is written and read, for example Digital Optical Recording (DOR). There are numerous applications in optoelectronic systems as well when such diodes are constructed as LEDs.

Such a radiati n-emitting diode and such a method of manufacturing it are known from the article by R. Maciejko et al., "Photoelastic Effects on the emission patterns of InGaAsP ridge-waveguide lasers" published in IEEE Journal of Quantum Electronics, vol. 25, no. 4, 4 April 1989, pp. 651-660. This describes a laser (see Fig. 2) in which an

found to occur mainly locally, i.e. approximately below the lateral sides of the ridge, and comprises a shift in the direction of and up to inside the first cladding layer. The invention is further based on the recognition that this local displacement is also partly caused by the stress in the structure present in situ. This stress promotes a local migration of atoms which give the second cladding layer the second conductivity type, for example zinc atoms, from the second cladding layer through the active layer to and into the first cladding layer. A pn junction which has been displaced (too far) results in degradation. The invention is finally based on the recognition that said displacement of the pn junction can be counteracted in that a barrier layer is provided between the second cladding layer and the active layer, i.e. a barrier obstructing the passage of dopant elements of the second conductivity type. The diode according to the invention, when constructed as a laser, has a particularly low degradation also at a low operating temperature: it is characterized by a total increase in the starting current of, for example, 5 %, whereas the known diode in that case shows an increase in the starting current of 100 %. It is noted that the expression "barrier layer between the active layer and the second cladding layer" is also understood to cover a barrier layer which is present within the active layer but in the portion thereof adjoining the second cladding layer as well as a barrier layer which is present within the second cladding layer at a small distance from the active layer, for example, separated therefrom by a so-called separate confinement layer. The barrier layer is thus effective at least for the major portion of the active layer or the major portion of the second cladding layer.

In a preferred embodiment of a radiation-emitting semiconductor diode according to the invention, the barrier layer comprises two or more sub-layers which have alternately a high and a low bandgap value. Such a barrier layer is found to be very effective in practice. A possible mechanism is that such a barrier layer prevents charge carriers, electrons in this case, from penetrating from the active layer into the cladding layer and giving off energy there which would promote a displacement of, for example, zinc atoms. If the barrier layer or the sub-layers is/are thin, for example thinner than 10 nm, they are allowed to have a mechanical stress without defects being caused thereby which would promote the degradation. Both a tension and a compression stress promote the effectivity of the barrier layer against, for example, zinc atoms: in the former case the lattice constant of the barrier layer is small(er), so that the zinc atoms, which are also small, are energetically stopped. In the latter case, the lattice constant of the barrier layer is great, so that it is indeed energetically favorable for the small zinc atoms to penetrate the barrier layer, but they are subsequently retained therein. The use of either kind of stress has the additional advantage

effective refractive index on either side of the ridge, and not a tension stress as in the known structure.

Preferably, the diode according to the invention is constructed as a laser, the substrate comprises n-type GaAs, the respective n-type and p-type cladding layers comprise AlGaInP or AlInP, the active layer comprises GaInP or AlGaInP with a lower aluminum content than the cladding layers, the diode comprises a contact layer of p-type GaAs, the second cladding layer is doped with zinc atoms, the barrier layer comprises two or more layers of AlGaInP or AlInP with alternately a high and a low aluminum content, and the covering layer which is under mechanical stress comprises a tantalum layer.

A method of manufacturing a radiation-emitting diode whereby a semiconductor body is formed through the provision on a semiconductor substrate of, in that order: at least a first cladding layer of the first conductivity type, an active layer, and a second cladding layer of a second conductivity type, the surface of the semiconductor body being provided with a covering layer which is under mechanical stress, and the surface of the semiconductor layer or the covering layer being geometrically structured such that, and the mechanical stress of the covering layer being chosen such that the effective refractive index for the radiation to be generated is reduced in the active layer on either side of a strip-shaped active region forming part of the active layer, is characterized according to the invention in that a barrier layer is provided between the active layer and the second cladding layer, which barrier layer prevents dopant atoms of the second conductivity type from moving from the second cladding layer into the active layer. A diode according to the invention is obtained in a simple manner by such a method.

Preferably, in a method according to the invention, zinc is chosen as the dopant of the second conductivity type, the barrier layer is formed by two or more sub-layers with alternately a high and a low bandgap, the doping levels of the cladding layers on either side of the active layer are provided stepwise from low to high, and a layer comprising tantalum is chosen for the covering layer, the latter being provided by diode sputtering at a high power or at a low argon pressure.

The invention will now be explained in more detail with reference to an embodiment and the accompanying drawing, in which

Fig. 1 is a diagrammatic cross-section of an embodiment of a radiation-emitting semiconductor diode according to the invention;

the radiation beam is forced underneath the mesa 12 and does not easily become filamented, but is rather more circular-symmetrical. The starting current of such a laser is also considerably lower than if the laser were of the gain-guided type, because in the latter case a so-called anti-guiding will arise in practice which leads to filamentation of the radiation beam and to an increase in the starting current of the laser.

According to the invention (see especially Fig. 2), a barrier layer 9 is present in the diode, so here in the laser, between the active layer 3 and the second cladding layer 4, which constitutes a barrier to dopant elements of the second conductivity type, so zinc atoms in this case, preventing at least that these doping elements move beyond the barrier layer into the active layer 3. The invention is based on a number of surprising finds and recognitions that a diode constructed as a laser shows a strong degradation especially at a low temperature of use; that this degradation is accompanied by, and indeed caused by a displacement of the pn junction; that this displacement is mainly local, i.e. approximately below the lateral edges of the mesa 12 and comprises a shift in the direction of and into the first cladding layer 2; that this local displacement is caused by the stresses present in the structure in situ, which stresses apparently promote migration of atoms which give the second cladding layer the second conductivity type, zinc atoms in this case, from the second cladding layer 4 through the active layer 3 to and into the first cladding layer 2; and finally that said displacement is counteracted by the application of a barrier layer 9 between the second cladding layer 4 and the active layer 3, thus raising a barrier to zinc atoms in this case which at least limits, or even prevents the displacement of said atoms altogether. The laser in this example shows a particularly low degradation also at a low operating temperature, for example in the case of pulsed operation: it is characterized by a total increase in the starting current of, for example, 3 %, whereas a laser comparable to the known diode shows a degradation of 100 % in that case. A diode according to the invention also has a very favorable degradation of, for example, 5 % at a higher temperature of use.

An important advantage of a diode according to the invention is that the barrier layer 9 not only constitutes a barrier to doping elements but is also capable of contributing to the efficiency. As a result, the laser in the present example has a particularly low starting current of, for example, 20 mA and a particularly low temperature-dependence of the starting current. The starting current is 75 % higher in a laser whose covering layer 7 has no mechanical stress or the wrong mechanical stress, i.e. a tension stress in this case.

In this example of a laser manufactured in the GaInP/AlGaInP material system, the barrier layer 9 is formed by two or more, in this case 20 sub-layers 9A, 9B with

comprising tantalum and gold of the metal layer 7 are provided. The sub-layer comprising tantalum is then given a sufficiently high compression stress, so that the resulting metal layer 7 will have the compression stress desired here (also after an unstressed layer comprising gold has been provided). The sub-layer comprising tantalum may be given a compression stress in that it is provided by diode sputtering at a comparatively low argon pressure, for example below approximately 25 μbar, or in that it is sputtered at a high power (for example during diode sputtering), in which case the temperature of the semiconductor body 10 becomes comparatively high, for example much higher than 300 °C, while the layer comprising tantalum is being provided. It is noted that a so-called annealing step should be avoided as much as possible here because any built-in compression stress is reduced by such a step or may even be converted into a tension stress.

The radiation-emitting semiconductor diode is constructed as a diode laser in this example. This means that the emission is coherent given a sufficient current strength. The strip-shaped mesa 12 is bounded perpendicularly to the longitudinal direction by two mutually parallel mirror surfaces lying in the plane of drawing and coinciding with natural cleaving surfaces of the crystal from which the semiconductor body was formed for the purpose of the diode laser version. This results in a resonant cavity for the generated radiation within the strips-shaped region 13 in the active layer 3.

The compositions, intentional doping concentrations, and thicknesses used for the various semiconductor layers in this example have been listed (once more) in the Table below.

preferably has a misorientation of at most 6 degrees relative to the (001) orientation, the following layers are grown on this surface, for example from the gas phase by means of OMVPE (- Organo Metallic Vapor Phase Epitaxy) in that order: the buffer layer 11, the first cladding layer 2, the active layer 3, the barrier layer 9 and the second cladding layer 4, the intermediate layer 5, and the contact layer 6. The materials, compositions, doping concentrations, and thicknesses for these layers are chosen as indicated in the Table above.

After the semiconductor layer structure thus obtained has been removed from the growing apparatus and has been cleaned in a usual manner, a strip-shaped mesa 12 is formed by etching through an SiO_2 mask 30 (see Fig. 4). The contact layer 6 is removed by means of an etchant comprising NH_3, H_2O_2, and H_2O in the ratio 2:1:50, the etching rate being approximately 0.7 μm/hour at room temperature. The intermediate layer 5 serves as an etching stopper layer. The mask 30 is subsequently removed, and the substrate 1 is grinded down to about 100 μm. Then the structure is introduced into a sputtering device upside down for providing the covering layer 7, i.e. a metal layer 7. First 50 nm Pt is provided. Then, in another sputtering process the metal layer 8 comprising AuGeNi is provided on the substrate 1. After removal from the sputtering device, the Pt is alloyed with the contact layer 6 of GaAs in an alloying oven at a temperature of 380 °C during 20 minutes in an argon atmosphere. After removal from the alloying oven and replacement in the sputtering device, the structure is given a 150 nm thick tantalum layer by means of diode sputtering at a power of 1000 watts and an argon pressure of $3x10^{-2}$ mbar. The tantalum layer is put under a compression stress of approximately 7 kbar thereby. Then a 50 nm thick gold layer is sputtered onto the tantalum layer, whereby the stress built up in the metal layer 7 is not changed anymore. After removal from the sputtering device, and after cleaving in two mutually perpendicular directions, the lasers obtained, having dimensions of, for example 300x300 μm^2, are ready for final mounting.

The invention is not limited to the embodiments given, since many modifications and variations are possible to those skilled in the art within the scope of the invention. Thus semiconductor materials or compositions of the chosen semiconductor materials other than those mentioned in the examples may be used, if so desired, such as those from the GaAs/AlGaAs or InP/InGaAsP material systems. Instead of weakly index-guided, the diode according to the invention may also be made strongly index-guided, which means that a major portion of the second cladding layer forms part of a mesa-type structure of the surface. The surface need not necessarily comprise a mesa. It is possible to provide a stress locally also in a flat semiconductor layer structure, such as a diode of the oxide strip

Claims:

1. A radiation-emitting semiconductor diode comprising a semiconductor body (10) with a semiconductor substrate (1) on which are present at least in that order a first cladding layer (2) of a first conductivity type, an active layer (3), and a second cladding layer (4) of a second conductivity type opposed to the first, the first and second cladding layers (2, 4) being provided with means (6, 7, 8) for the supply of an electric current and with a pn junction which, given a sufficiently high current strength in the forward direction, is capable of generating electromagnetic radiation in a strip-shaped active region (13) of the active layer (3), while the surface of the semiconductor body (10) is provided with at least one covering layer (7) which is under mechanical stress and the surface of the semiconductor body (10) or the covering layer (7) is geometrically structured such that, and the mechanical stress of the covering layer (7) is chosen such that the effective refractive index for the generated radiation is reduced in the active layer (3) on either side of the strip-shaped active region (13), characterized in that a barrier layer (9) preventing the diffusion of dopant elements of the second conductivity type from the second cladding layer (4) into the active layer (3) is present between the active layer (3) and the second cladding layer (4).

2. A radiation-emitting semiconductor diode as claimed in Claim 1, characterized in that the barrier layer (9) comprises two or more sub-layers (9A, 9B) which have alternately a high and a low bandgap value.

3. A radiation-emitting semiconductor diode as claimed in Claim 1 or 2, characterized in that the barrier layer (9) has a mechanical stress and preferably partly has a compression stress, partly a tension stress.

4. A radiation-emitting semiconductor diode as claimed in Claim 1, 2 or 3, characterized in that the doping concentration at at least one side of the active layer (3), but preferably on both sides thereof, has a gradient, preferably stepwise, from a low concentration to a high concentration.

5. A radiation-emitting semiconductor diode as claimed in Claim 1, 2, 3 or 4, characterized in that the surface of the semiconductor body (10) is geometrically structured in that the semiconductor body (10) is provided with a strip-shaped mesa (12) which comprises at most a portion of the second cladding layer (4) and which is present

of the second conductivity type is provided on the second cladding layer (4), the surface of the semiconductor body (10) is geometrically structured through the provision of a strip-shaped mesa (12) which comprises the contact layer (6), and the covering layer (7) is provided over the strip-shaped mesa (12) and on either side (14, 15) thereof and is provided with a compression stress.

10. A method as claimed in Claim 8 or 9, characterized in that zinc is chosen as the dopant of the second conductivity type, the barrier layer (9) is formed by two or more sub-layers (9A, 9B) with alternately a high and a low bandgap value, the cladding layers (2, 4) on either side of the active layer (3) are first weakly doped and farther removed from the active layer (3) strongly doped, and a layer (7) comprising tantalum is chosen for the covering layer (7) and is provided by diode sputtering at a high power or at a low argon pressure.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 97/00612

C (Continuati n). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of d cument, with indication, where appropriate, of th relevant passages	Relevant to claim No.
A	EP 0518320 A2 (SUMITOMO ELECTRIC INDUSTRIES LIMITED), 16 December 1992 (16.12.92), column 2, line 27 - column 3, line 56, figures 1-7, claims 1-11	1-10
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A	EP 0390262 A1 (N.V. PHILIPS' GLOEILAMPENFABRIEKEN), 3 October 1990 (03.10.90), see the whole document.	1-10
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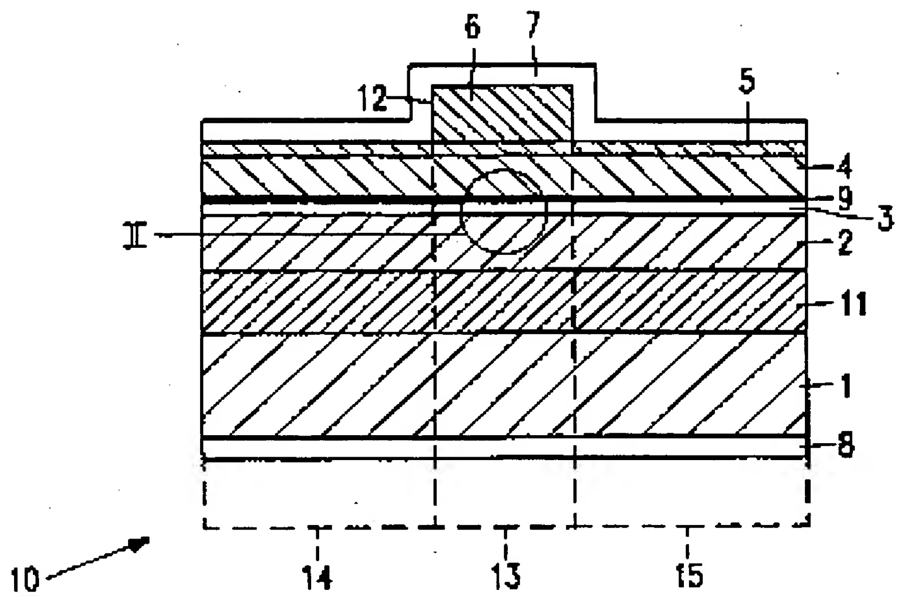

FIG. 1

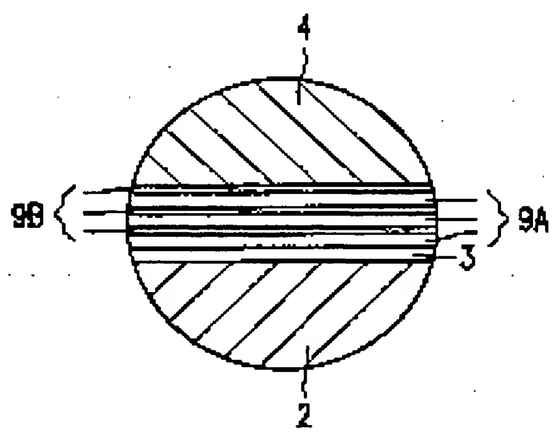

FIG. 2

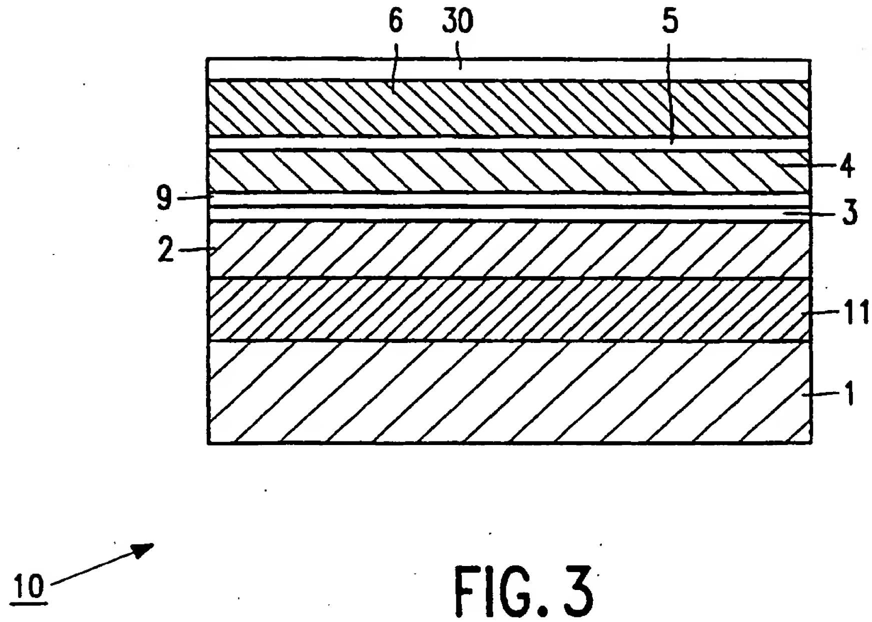

FIG. 3

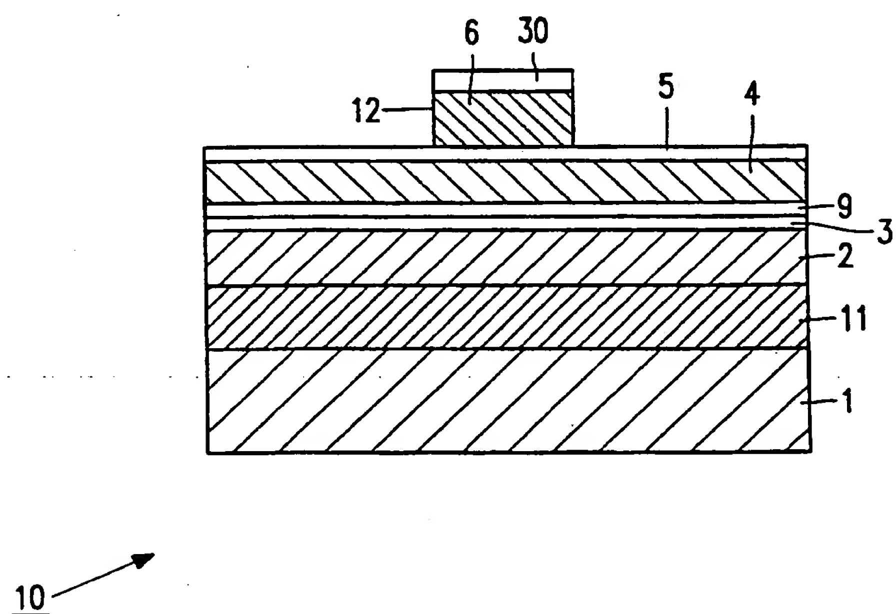

FIG. 4